Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com
J P P
Journal of Pharmacognosy and Phytochemistry

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(4): 1739-1744
Received: 19-05-2018
Accepted: 24-06-2018

Evaluation of different methods of Zinc application on growth and yield of hybrid rice (*Oryza sativa* L.) in inceptisol of Varanasi

Surendra Singh Jatav and Satish Kumar Singh

Surendra Singh Jatav
Department of Soil Science and Agriculture Chemistry, Institute of Agriculture sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Satish Kumar Singh
Department of Soil Science and Agriculture Chemistry, Institute of Agriculture sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Abstract

A pot experiment was conduct to assess the effect of various methods of Zn application on growth and yield of hybrid rice. Treatments consist of; without fertilizer, RDF (NPK), Zn-soil application, ZnO- root dipping, Zn-foliar application, soil + root dipping, soil+ foliar, root dipping+ foliar, soil + root dipping +foliar. Results showed that the Zn application by different methods significantly increased plant height, number of tiller, chlorophyll content, number of panicle, length of panicle, grain panicle^{-1}, straw yield, grain yield and 1000 grains weight. Maximum grain yield of rice was recorded in T_9 (SA+RD+FS) in which conjoint application of Zn was made following all the methods of Zn application. This treatment (T_9) also had the highest DTPA-extractable Zn content (1.18 mg kg^{-1}) in post-harvest soil.

Keywords: hybrid rice, Zn application methods, growth, yield

Introduction

The dynamics of zinc in soils, water and plants are important in achieving sustainable solutions to address the problem of Zn deficiency in crops and humans (Noulas *et al.*, 2018) [1]. Zinc (Zn) is one of the essential micronutrients for plants especially for rice growing under submerged conditions (Naik *et al.*, 2007) [2]. It is one of the most essential micronutrients required for the growth and development of plant and human beings. One-third of the human population, including children and women suffer from Zn deficiency related health problems such as growth retardation, lack of appetite, lack of immune function, hair loss, diarrhoea, vision, and skin lesions, weight loss, delayed healing of wounds, and mental lethargy Hotz and Brown (2004) [3]. The lack of micronutrients has become the major nutritional problem affecting more than two billion people in both developed and developing countries of Asia, Africa and Latin America (Alloway 2008) [4] (Swamy *et al.*, 2016) [5]. Micronutrient deficiencies or "hidden hunger" affects approximately 38% of pregnant women and 43% of preschool children worldwide and the most widespread among developing countries.

Zinc deficiency has emerged as the fourth important micronutrient deficiency in humans. It's responsible for diarrhoea in infants, dwarfism in adolescents and loss of disability adjusted life years (DALYs) in adults (Prasad 2013) [6]. Zinc plays an important role in many biological processes and is a necessary trace element for the proper growth and reproduction of plants, and the health of animals and humans. Zinc deficiency problem has received increasing attention and appears to be the most serious micronutrient deficiency together with vitamin A deficiency (Cakmak 2009) [7].

The crops have started responding to micronutrient fertilizers in view of the widespread deficiency of micronutrients such as zinc, boron and to a limited extent iron, manganese, copper and Molybdenum (Gupta 2005) [8]. Increasing zinc concentration in rice grain has twain benefits for human nutrition health and also increasing crop production through better germination and seedling vigour of rice plants grown on soils with limited Zn supply (Phattarakul *et al.*,2012) [9]. Zinc is one of the essential micronutrients, which serves as a co-factor for more than 300 enzymes involved in the metabolism of carbohydrates, lipids, proteins, and nucleic acids, hence is important for normal growth and development of plants and animals (Roohani *et al.,2013*; Sadeghzadeh 2013) [10, 11]. It is estimated that agricultural production must increase by 70% by 2050 to feed over 9 billion people worldwide. India is no exception. Analysis of over 256,000 soil samples from all over India showed that about 50% of the soils were deficient in zinc and that this was the most common micronutrient problem affecting crop yields in India (Singh 2009) [12]. Wheat and rice is major staple food in India constitute about 60-70% of daily calorie uptake.

Correspondence
Satish Kumar Singh
Department of Soil Science and Agriculture Chemistry, Institute of Agriculture sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India

The rice grain are very low in Zn content and contain anti - nutrition compound like phytates which reduced bioavaility of Zn (Kumar 2016) [13].

Rice is the main food for half the world population. On a global basis, rice provides dietary energy and proteins to the extent of 21% and 15% per person, respectively (McLean *et al.*, 2002) [14]. Rice is a major food crop in India especially in West Bengal. The availability of most of nutrients in the soil increases when the submergence, but the availability of Zn for the plant is reduced (Westfall *et al.*, 1971; Romheld *et al.*, 1991) [15, 16]. Pre Sowing Soil application of zinc fertilizer is most common method to correct of Zn deficiency problem in rice crop Singh and Shivey (2015) [17]. It has been reported that basal Zn fertilizer may have a strong residual effect, but in some soils, (calcareous and slightly alkaline), Zn can be fixed and is, therefore, not utilized by the crop (Rengel, 2015) [18]. Foliar Zn application under such conditions could be more effective than other methods of Zn application. Effective method for correction of Zn deficiency in plant and increasing its concentration in grain but its effectiveness depended on time and methods of application (Phattarakal *et al.*, 2012) [9]. The effectiveness of Zn application methods varies widely depend upon nature of soil, crops and fertilizers. The present study intend to evaluate various methods of Zn application in a bid to find out a suitable proposition to satisfy the Zn requirement of hybrid rice in an Inceptisol of Varanasi.

2. Material and Methods

2.1 Experimental site and soil properties

A pot experiment was conducted with hybrid rice (*Oryza sativa* L.) variety Arize-6444 during *Kharif* season of 2015-016 in the net house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. The Varanasi is Situated at an altitude of 80.71 meters above mean sea level and located between 25^0 14 and 25^0 23 N latitude and 82^0 56 and 83^0 30E longitude has a semi-arid to sub humid climate with moisture deficit index between 20-40. The average annual rainfall of this region is about 1100 mm. Generally, the maximum and the minimum temperature ranged between 20^0 - 42^0 C and 9^0 - 28^0 C, respectively. May and June are the hottest months with the maximum temperature ranging from 39^0 to 42^0 C. The cold period lies between November and January with the minimum temperature varying between 9^0-10^0 C. The mean relative humidity is about 68% which rise to 82% during wet season and goes down to 30% during dry season. The bulk soil (0-15 cm depth) sample was collected from BHU's agricultural research farm had pH 8.21 (Sparks 1996)) [19]; electrically conductivity 0.19 dS m^{-1} (Sparks 1996) [19]; Organic carbon 0.42%, Walkley and Black, (1934) [20]; available N 82.25 kg ha^{-1} Subbiah and (Asija 1956) [21]; available P 35.52 kg ha^{-1}, (Olsen, 1954) [22]; and available K 175.95 kg ha^{-1} (Hanway and Heidal, 1952) [23]. The DTPA-extractable zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) contents in soil were 0.58, 2.33, 30.0 and 6.53 mg kg^{-1}, respectively (Lindsay and Norwell 1978) [24]. analysed by using atomic absorption spectrophotometer (UNICAM 969).

2.2 Crop management

The recommended dose of fertilizer (RDF) for hybrids rice is 150:60:60 N, P_2O_5 and K_2O. Required quantities of fertilizers for 10 kg soil was calculated and applied in liquid form using Urea $CO(NH_2)_2$), Potassium dihydrogenphosphate (KH_2PO_4) and muriate of potash (KCl) as source of N, P_2O_5 and K_2O, respectively. Full dose of P_2O_5 and K_2O and half dose of N were applied before transplanting and remaining nitrogen was added in two equal splits at 30 and 60 days after transplanting in each pot. The growth and yield attribute recorded at different stage after transplanting of hybrid rice. The treatment details are given in Table 1.

2.3 Statistical analysis

The data were subjected to one-way analysis of variance (ANOVA) using SPSS version 16 software. Duncan's multiple range test (DMRT) was performed to test the significance of difference between the treatments.

3. Result and Discussion

3.1 Morphological traits

3.1 1Plant height

All growth attributes (plant height, chlorophyll content and numbers of tillers) showed a highly significant response to various methods of application of Zn fertilizer (Table 2). At 30 DAT, maximum plant height 81.29 cm was obtained by Zn application through root dipping while lowest 60.06 cm in absolute control (T_1) (Table 2). As compare to absolute control, plant height increased 16.79%, 11.39%, 11.96%, 13.06% and 15.58% by root dipping (RD), foliar spray(FS), soil application (SA) + root dipping, root dipping + foliar and soil application + root dipping+ foliar spray, respectively. At 60 DAT, maximum plant height of 111.7 cm was recorded with SA + FS followed by RD + FS (107.23cm) and FS (106.00cm). (Table 2). At 90 DAT, application of Zn through SA, FS, SA+FS produced significantly higher plant height over absolute control (T_1) (Table 2). The maximum height (6.62% increases over control) was observed in T_7 (SA+FS) in which the maturity of grains was delayed and height was considerably more. Zinc application significantly increased the plant height which might be attributed to the adequate supply of zinc to accelerate the enzymatic activity and auxin metabolism in plants. These results are in agreement with the findings of (Khan *et al.*, 2007; and Sudha *et al.*, 2015; Abdoli *et al*., 2014) [25, 26, 27]. Who reported a significant increase in plant height in safflower and bread wheat plants treated with foliar Zn application compared withcontrol. Similar results were also observed by (Saha *et al*., 2013) [28].

3.1.2 Chlorophyll content

At 30 DAT, the maximum chlorophyll content (SPAD value 36.62) was observed when Zn was through RD (T_4) (Table 2). All the Zn application methods were stastically at par to each other with respect to chlorophyll content in leaf, however, they increased chlorophyll content over T_1(without fertilizers) and T_2 (RDF). At 60 DAT, the minimum chlorophyll content (SPAD 25.67) was recorded in treatment T_2 (RDF) whereas the maximum chlorophyll content (SPAD 40.31) was recorded in treatment T_7 (RDF+SA+FS) (Table 2).The treatment root dipping, foliar spray, root dipping +foliar spray, and soil application + root dipping + foliar spray were found at par in chlorophyll content. At 90 DAT, the minimum chlorophyll content (SPAD 23.85) was recorded in treatment T_4 (RD) whereas maximum chlorophyll content (31.77) was recorded in treatment T_8 (RD+FS).There is no significant increase in chlorophyll content (SPAD VALUE) at 90 DAT (Table 2). Similar results were also found by (Yoshida *et al.*, 1970) [29]. Zinc helps in the formation of chlorophyll through the regulation of homeostasis (Aravind and Prasad, 2004) [30].

3.1.3 Number of tillers

At 30 DAT, highest number of tillers (6) were obversed in application of Zn through RD (T_4) followed by 5.87 in

RD+FS (T_8)) with respective increase of 45.27 and 42.13 % T_2 (RDF). (Table 2). At 60 DAT, the number of tillers increased significantly in every Zn applied treatment, however, all the treatments received in one foliar spray i.e.T_5, T_7, T_8 and T_9 had higher number of tillers showing an increase of 22.62, 65.10, 67.77 and 88.49%, respectively over T_2 (RDF) (Table 2). At 90 DAT, slight decrease in number of effective tillers compared to observations at 60 DAT in all the treatments were recorded due to reduction in number of effective tillers. Although, effective tillers were more in Zn applied treatments. Tillering capacity is one of the most important rice components which are responsible for yield of crop. The increased tillers number by Zn application may be attributed to its role in various Zn induced enzymatic activity and auxin metabolism which control growth of plant. These results are similar to the findings of Ghani *et al*., (1990) [31].

3.2 Yield attributes and yield

The various methods of application of Zn fertilizers also showed a significant response on number of panicle, grains panicle^{-1} straw and grain yield and weight of 1000 grains (Table 3). The treatment T_5 produced maximum number of panicles (5.87) followed by T_8 (5.80) which was 31.31 and 29.75% significantly higher over RDF (T_2) (Table 3). Although, T_4 (RD), and T_6 (SA+RD) produced higher number of panicles than T_2 (RDF) but were statistically at par to each other. (Srivastava *et al.*, 1999) [32]. reported a significantly higher number of emerged panicles pot^{-1} compared to the controls from 80 to 93 with Zn applications. (Yilmaz *et al*., 1997) [33] also found significant effects of Zn application methods on the number of spike m^{-2} in wheat, particularly by soil and soil + leaf applications. Marschner (1995) [34] reported that zinc is required for the synthesis of tryptophan, the precursor of indole acetic acid (IAA). Therefore, Zn application might have increased IAA synthesis leading to increase in plant height via increase in internode length as well as number of panicle. These results are in agreement with (Movahhedy-Dehnavy *et al*., 2009) [35]. The length of panicle increased significantly with the application of Zn through various methods (Table 3). The treatment T_7 (SA+FS) followed by T_4 (RD) increased length of panicle to a tune of 13.79 and 9.31% over T_2 (RDF). The treatment T_5, T_6, T_8 and T_9 were stastically at par to each other (Table 3). Similar results were also observed by Saha *et al*., (2013) [28].

Application Zn through soil and root dipping T_6 (RDF+SA + RD) resulted in significantly higher (126.63) grain pancle-^{1} which was 5.67% over the treatments T_2 (Table 3). Other Zn application treatments were stastically similar with respect to grain panicle^{-1} (Esfandiari *et al.*, 2016) [36]. States that as the application of spray and soil application, there has been an increase in the absorption of N, P and K as well as enhanced crop yield and its components. Thus combining any two modes appears useful (Yilmaz *et al*., 1997) [33] reported significant effects of Zn application methods on the grain number spike^{-1} in wheat. Iron-zinc (applied as ferrous sulphate and zinc sulphate on the soil) was found to increase, ear head length, number of grains per ear, grain yield per plant and weight in ratio to 1000 grains significantly (Hemantaranjan *et al*., 1988) [37].

The maximum grain yield of rice (37.91 g pot^{-1}) was noticed when all modes of Zn application were combined T9 (SA+RD+FS) with RDF which was stastically superior compared to all other methods. All the methods of Zn application produces significant increase in rice grain yield except application by foliar mode (T_5). The straw yield of hybrid rice was also highest (55.71 g pot^{-1}) in T_9 (SA+RD+FS) which was stastically superior over T_2 (RDF) in which no Zn was applied (Table 3). Supply of Zn inT_9 by a combination of root dipping, soil application and foliar sprays might have made adequate availability of Zn which has facilitated the growth of the plant, due to its involvement in many metallic enzyme system, regulatory functions and auxin production (Sachdev *et al*., 1988) [38] increased synthesis and transport of carbohydrates to the sink (PeddaBabu *et al*., 2007 Muthukumararaja *et al.*, 2012. Wang *et al*., 2014) [39, 40, 41] and (Imran *et al.*, 2015) [42] also reported increase in straw yield with application of Zn.

The highest test weight (24.17 g) in hybrid rice was obtained through soil application + root dipping + foliar spray (T_9) followed by soil application + foliar spray (T_7) while absolute control(T_1) had minimum test weight of 18.57g (Table 3). Our result are agreement with (Bandara and Silva 2000; Rahman *et al.*, 2008) [43, 44] who also reported an increase in test weight upon Zn application but the effect was non-significant. Increased test weight of rice cultivars upon Zn fertilization might be due to the increase in carbonic anhydrase activity and more carbohydrate accumulation in the seeds.

3.3 Properties of postharvest soils

The Soil pH varied from 8.21 to 8.57 the maximum being in treatment T_1 (absolute control) followed by T_4 (RD), T_5 (FS) and T_8 (RD+FS) (Table 4). The effect of various methods of Zn application does not show significant impact on soil pH. (Cayton *et al.*, 1985) [45] reported that Zn addition increased pH in marginally Zn-deficient soil. Decrease in soil pH may be attributed to crop root acid produced in soil. Similar results have been reported by (Dhaliwal *et al*., 2012) [46].

It is evident that the EC of soil ranged from 0.16 to 0.23 dS m^1. The minimum value of EC (0.16 dSm^{-1}) was recorded in T_4 (RD) and the maximum EC (0.23) was in T_9 (SA + RD + FS). Treatment T_6, T_7 and T_9 produced a significant increase in EC of soil, although the effect of other methods of Zn application was non significant. (Verma *et al.*, 1984) [47] reported that the interactions between EC and Zn levels were not found to be significant.

The organic carbon content of the soils varied from 0.27 to 0.51 %. The minimum organic carbon content of 0.27% was found in treatment T_9 (SA+RD+FS), followed by T_8 (RD+FS) and T_4 (RD) (Table 4).

The DTPA extractable Zn in the post-harvest soil varied between 0.77 to 1.18 mg kg^{-1} the maximum being in the treatment in which Zn was applied through all the modes of Zn application (T_9). Among the various treatments T_6 (SA + RD), T_8 (RD+FS) and T_9 (SA+RD+FS) registered a significant increase in DTPA- extractable Zn in post-harvest soil over T_2 (RDF) and T_1 (Without fertilizers) (Table 4). The maximum Zn content found treatment T_9 followed by T_8 which were 50.72 and 38.46% higher over T_2 (RDF). The study revealed that combination of various methods of Zn application for rice was useful in increasing grain yield. The study being pot experiment, reflects scientific issues which needs to be tested at field conditions to arrive at final recommendation of Zn application in rice in Inceptisol of Varanasi.

Table 1: About the method of Zn application and symbols are used to treatment

Treatments	**Methods of application**	**Symbol**
T_1:	Without Fertilizer	(WF)
T_2:	Control: RDF (N: P_2O_5: K_2O @ 150:60:60 kg ha^{-1})	Control (RDF)
T_3:	RDF + 5.0 kg Zn ha^{-1} soil application	RDF + SA
T_4:	RDF + 2% ZnO root dipping	RDF + RD
T_5:	RDF + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage	RDF + FS
T_6:	RDF + 5.0 kg Zn ha^{-1} soil application + 2% ZnO root dipping	RDF + SA +RD
T_7:	RDF + 5.0 kg Zn ha^{-1} soil application + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage	RDF + SA + FS
T_8:	RDF + 2% ZnO root dipping + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage	RDF + RD + FS
T_9 :	RDF + 5.0 kg Zn ha^{-1} soil application + 2% ZnO root dipping + (0.5% $ZnSO_4$ + 0.25% Lime) foliar spray at tillering and milking stage	RDF + SA +RD + FS

Table 2: Effect of different methods of Zinc application on plant height, chlorophyll content and number of tillers in hybrid rice (mean of 3 replicates ± SE)

Treatment*	**Plant height (cm)**			**Chlorophyll content (SPAD)**			**Number of tillers pot^{-1}**		
	30 DAT	**60 DAT**	**90 DAT**	**30 DAT**	**60 DAT**	**90 DAT**	**30 DAT**	**60 DAT**	**90 DAT**
T_1	69.60 ± 0.53 e	79.78 ±0.22 f	96.33 ± 0.58 f	29.81 ±0.24 b	33.80 ±0.20 d	27.07± 4.21abc	2.87±0.06f	3.60±0.01e	2.27±0.17e
T_2	74.57 ± 0.32 d	100.33 ± 1.86 de	108.73 ± 1.45 cde	31.80 ±1.97 b	40.08 ±0.56cd	25.68± 0.61bc	4.13±0.06e	5.13±0.46d	4.07±0.06d
T_3	76.89 ± 1.66 cd	103.07 ± 0.52 cd	114.53 ± 1.07 ab	35.28 ±0.28 a	39.33 ±0.85cd	30.76± 0.94ab	5.33±0.13c	5.69±0.50cd	4.33±0.06cd
T_4	81.29 ± 0.60 a	104.17 ± 0.94c	111.80 ± 1.40 abcd	36.62 ±0.39 a	38.57 ±0.74cd	23.85±0.94 c	6.00±0.00a	5.67±0.33cd	4.87±0.29bc
T_5	77.53±0.18 bcd	106.00 ± 1.00bc	113.27 ± 1.07 abc	36.01 ±0.53 a	38.22 ±0.45bc	27.47±0.83abc	4.07±0.18e	6.29±0.36c	4.27±0.33cd
T_6	77.93 ±0.82 bc	104.33 ± 0.67 bc	110.87 ± 1.67 bcde	36.54 ±0.29 a	37.47 ±0.42bc	28.56± 2.28abc	4.67±0.17d	8.27±0.33b	5.00±0.30b
T_7	76.47 ± 0.97 cd	111.17 ± 0.66 a	115.93 ± 1.87 a	35.26 ±0.72 a	40.31 ±0.28a	27.23±0.70 abc	5.73±0.13ab	8.47±0.67b	5.20±0.20b
T_8	78.69 ±1.33 abc	107.23 ± 11.24 b	106.73 ± 0.47 e	36.51 ±0.48 a	38.56 ± 0.75ab	31.77± 1.04a	5.87±0.06a	8.60±0.11b	5.07±0.13b
T_9	80.45 ± 0.93 ab	100.06 ±0.07 e	107.80 ± 2.40de	35.16 ± 0.50 a	38.81±0.33a	30.18± 0.44ab	5.47±0.06bc	9.67±0.33a	5.93±0.13a

* - T_1: without fertilizer (WF) T_2: Control (RDF), T_3: RDF + SA, T_4: RDF + RD, T_5: RDF + FS, T_6: RDF + SA + RD, T_7: RDF + SA + FS, T_8: RDF + RD+FS, T_9: RDF+SA+RD+FS

Table 3: Effect of different methods of Zinc application on number of panicles, length of panicle, number of grains, straw yield, grain yield and 1000 grain weight of hybrid rice (mean of 3 replicates ± SE).

Treatment*	**Number of panicles**	**Length of Panicle(cm)**	**Grain panicle^{-1}**	**Straw yield (g pot^{-1})**	**Grain yield (g pot^{-1})**	**Test weight(g)**
T_1	3.20±0.00d	22.11±0.52d	81.20±0.50d	15.87±1.19c	11.31±0.38e	18.57±0.02d
T_2	4.47±0.06c	22.50±0.37cd	119.83±2.07ab	44.13±6.58ab	24.09±1.37d	19.70±0.82cd
T_3	5.20±0.11b	24.53±0.78ab	114.67±2.26bc	47.10±1.12ab	29.98±1.39c	19.32±0.37cd
T_4	4.53±0.06c	24.81±.29ab	115.47±4.58bc	47.07±3.36ab	33.12±1.09b	19.63±0.24cd
T_5	5.87±0.17a	24.81±0.29ab	110.67±4.46c	44.73±6.76ab	23.94±1.28d	20.72±0.86bc
T_6	4.53±0.33c	24.13±0.09bc	126.63±2.41a	47.12±2.80ab	29.33±0.42c	20.73±0.73bc
T_7	4.47±0.042c	26.10±0.10a	121.07±1.24ab	43.39±1.83ab	32.25±1.04bc	22.740.32±a
T_8	5.80±0.40ab	24.68±0.13ab	122.50±1.47ab	36.54±8.10b	31.16±0.46bc	22.40±0.71ab
T_9	5.68±0.01ab	24.53±0.13ab	117.00±0.58bc	55.71±2.09a	37.91±0.31a	24.17±0.48a

*- T_1: without fertilizer (WF), T_2: Control (RDF), T_3: RDF + SA, T_4: RDF + RD, T_5: RDF + FS, T_6: RDF + SA + RD, T_7: RDF + SA + FS, T_8: RDF + RD+FS, T_9: RDF+SA+RD+FS.

Table 4: Effect of different Zn treatments on post-harvest soil properties (mean of 3 replicates ± SE)

Treatment*	**pH**	**EC (dS m^{-1})**	**OC (%)**	**Zn (mg kg^{-1})**
T_1	8.57±0.06a	0.17±0.04b	0.45±0.02abc	0.77±0.06c
T_2	8.31±0.02ab	0.18±0.01b	0.47±0.03ab	0.78±0.06c
T_3	8.43±0.06ab	0.17±0.01b	0.44±0.09abc	0.94±0.06bc
T_4	8.53±0.10ab	0.16±0.00b	0.32±0.02cd	0.91±0.06bc
T_5	8.50±0.08ab	0.17±0.01b	0.48±0.04ab	0.87±0.06bc
T_6	8.43±0.06ab	0.19±0.00a	0.51±0.02ab	1.02±0.06ab
T_7	8.45±0.03ab	0.19±0.00a	0.35±0.06bcd	0.99±0.07abc
T_8	8.38±0.22ab	0.18±0.01b	0.29±0.00d	1.08±0.11ab
T_9	8.21±0.11b	0.23±0.02a	0.27±0.05d	1.18±0.06a

* - T_1: without fertilizer (WF), T_2: Control (RDF), T_3: RDF + SA, T_4: RDF + RD, T_5: RDF + FS, T_6: RDF + SA + RD, T_7: RDF + SA + FS, T_8: RDF + RD + FS, T_9: RDF + SA + RD + FS

References

1. Noulas C, Tziouvalekas M, Karyotis T. Zinc in soils, water and food crops. Journal of Trace Elements in Medicine and Biology, 2018.
2. Naik SK, Das DK. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) In an inceptisol. Archives of Agronomy and Soil Science. 2007; 53(3):305-313.
3. Hotz C, Brown KH. Assessment of the risk of zinc deficiency in populations and ptions for its control. Food and Nutrition Bulletin. 2004; 25:94-204.
4. Alloway BJ. Zinc In Soils And Crop Nutrition. Edn 2, IZA, IFA, Brussels, 2008, 1-135.
5. Swamy BM, Rahman MA, Inabangan-Asilo MA, Amparado A, Manito C *et al*. Advances in breeding for high grain Zinc in Rice. Rice. 2016; 9(1):49.

6. Prasad R, Shivay YS, Kumar D. Zinc fertilization of cereals for increased production and alleviation of zinc malnutrition in India. Agricultural Research. 2013; 2(2):111-118.
7. Cakmak I. Enrichment of fertilizers with zinc: An excellent investment for humanity and crop production in India. Journal of Trace Elements in Medicine and Biology. 2009; 23:281-289.
8. Gupta AP. Micronutrient status and fertilizer use scenario in India. Journal of Trace Elements in Medicine and Biology. 2005; 18:325-331.
9. Phattarakul N, Rerkasem B, Li LJ, Wu LH, Zou CQ, Ram H *et al*. Biofortification of rice grain with zinc through zinc fertilization in different countries. Plant and Soil. 2012; 361(1-2):131-41.
10. Roohani N, Hurrell R, Kelishadi R, Schulin R. Zinc and its importance for human health: An integrative review. Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences. 2013; 18(2):144.
11. Sadeghzadeh B. A review of zinc nutrition and plant breeding. Journal of Soil Science and Plant Nutrition. 2013; 13:905-927.
12. Singh MV. Micronutrient nutritional problems in soils of India and improvement for human and animal health. Indian Journal of Fertilisers. 2009; 5(4):11-56.
13. Kumar A, Denre M, Agarwal BK, Kumar M, Ojha RK. Agronomic Bio-fortification of Zinc in Indigenous High Yielding and Hybrid Rice (*Oryza sativa* L.) Cultivars**.** Journal of the Indian Society of Soil Science. 2016; 64:93-97.
14. Maclean JL, Dawe DC, Hardy B, Hettel GP. Rice almanac. Edn3, CABI Publishing, Wallingford, UK, CABI Publishing, 2002, 253.
15. Westfall DG, Anderson WB, Hodges RJ. Iron and zinc response of chlorotic rice grown on calcareous soils1. Agronomy Journal. 1971; 63(5):702-705.
16. Romheld V, Marschner H. Function of micronutrients in plants. Micronutrients in agriculture. 1991; 2:297-328.
17. Shivay YS, Prasad R, Singh RK, Pal M. Relative efficiency of zinc-coated urea and soil and foliar application of zinc sulphate on yield, nitrogen, phosphorus, potassium, zinc and iron biofortification in grains and uptake by basmati rice (*Oryza sativa* L.). Journal of Agricultural Science. 2015; 7(2):161.
18. Rengel Z. Availability of Mn, Zn and Fe in the rhizosphere. Journal of soil science and plant nutrition 2015; 15(2):397-409.
19. Sparks DL, Helmke PA, Page AL. Methods of soil analysis: Chemical methods, V3 SSSA, 1996.
20. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil science. 1934; 37(1):29-38.
21. Subbiah B, Asija GL. Alkaline permanganate method of available nitrogen determination. Current Science. 1956; 25:259.
22. Olsen SR. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture, Washington, 1954.
23. Hanway JJ, Heidel H. Soil analyses method as used in Iowa State College Soil Testing Laboratory. Iowa Agaric. 1952; 57:1-31.
24. Lindsay WL, Norwell WA. Development of DTPA soil test for Zn, iron, man-ganese and copper. Soil Science Society of America Journal. 1978; 42:421-428.
25. Khan MU, Qasim M, Khan I. Effect of Zn fertilizer on rice grown in different soils of Dera Ismail Khan. Sarhad Journal of Agriculture. 2004; 23:1033-1040.
26. Sudha S, Stalin P. Effect of zinc on yield, quality and grain zinc content of rice genotypes. International Journal of Farm Sciences. 2015; 5(3):17-27.
27. Abdoli M, Esfandiari E, Mousavi SB, Sadeghzadeh B. Effects of foliar application of zinc sulfate at different phenological stages on yield formation and grain zinc content of bread wheat (cv. Kohdasht). Azarian Journal of Agriculture. 2014; 1:11-17.
28. Saha B, Saha S, Roy PD, Hazra GC, Das A. Zinc fertilization effects on agromorphological and quality parameters of commonly grown rice. SAARC Journal of Agriculture. 2014; 11(1):105-20.
29. Yoshida S, Tanaka A. Zinc deficiency of the rice plant in calcareous soils. Soil Science and Plant Nutrition. 1970; 15(2):75-80.
30. Aravind P, Prasad MNV. Zinc protects chloroplasts and associated photochemical functions in cadmium exposed Ceratophyllum demersum L. a Fresh water macrophyte. Plant Science. 2004; 166:1321-132.
31. Ghani A, Shah M, Khan DR. Response of rice to elevated rates of zinc in mountainous areas of Swat. Sarhad Journal of Agriculture. 1990; 6(4):411-415.
32. Srivastava PC, Ghosh D, Singh VP. Evaluation of different zinc sources for lowland rice production. Biology and fertility of soils. 1999; 30(1-2):168-72.
33. Yilmaz A, Ekiz H, Torun B, Gultekin I, Karanlik S, Bagci SA *et al*. Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. Journal of plant nutrition. 1997; 20(4-5):461-71.
34. Marschner H. Mineral nutrition of higher plants. Edn2, Academic Press Inc, Cambridge, 1995, 890.
35. Movahhedy-Dehnavy M, Modarres-Sanavy SAM, Mokhtassi-Bidgoli A. Foliar application of zinc and manganese improves seed yield and quality of safflower (*Carthamus tinctorius* L.) grown under water deficit stress. Industrial Crops and Products. 2009; 30(1):82-92.
36. Esfandiari E, Abdoli M, Mousavi SB, Sadeghzadeh B. Impact of foliar zinc application on agronomic traits and grain quality parameters of wheat grown in zinc deficient soil. Indian Journal of Plant Physiology. 2016; 21:263-270.
37. Hemantaranjan A, Garg OK. Iron and zinc fertilization with reference to the grain quality of triticum aestivum L. Journal of Plant Nutrition. 1988; 11(6):1439-1450.
38. Sachdev P, Deb DL, Rastogi DK. Effect of varying levels of zinc and manganese of drymatter yield and mineral composition of wheat plant at maturity. Journal of Nuclear Agriculture and Biology. 1988; 17(3):137-43.
39. Peda Babu P, Shanti M, Rajendra Prasad B, Minhas PS. Effect of zinc on rice in rice–black gram cropping system in saline soils. Andhra Agricultural Journal. 2007; 54(1-2):47-50.
40. Muthukumararaja TM, Sriachandrasekharan MV. Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. Journal of Agricultural Technology. 2009; 8:551-561.
41. Wang YY, Wei YY, Dong LX, Lu LL, Feng Y, Zhang J *et al*. Improved yield and Zn accumulation for rice grain

by Zn fertilization and optimized water management. Journal of Zhejiang University Science. 2014; 15(4):365-74.

42. Imran M, Kanwal S, Hussain S, Aziz T, Maqsood MA. Efficacy of zinc application methods for concentration and estimated bioavailability of zinc in grains of rice grown on a calcareous soil. Pakistan Journal of Agriculture Science. 2015; 52:169-175.
43. Bandara WM, Silva LC. Rice crop response to zinc application in low humic gley soils of low country intermediate zone. Journal of Soil Science Society Sri Lanka. 2000; 12:40-50.
44. Roohani N, Hurrell R, Kelishadi R, Schulin R. Zinc and its importance for human health: An integrative review. Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences. 2013; 18(2):144.
45. Cayton MTC, Reyes ED, Neue HU. Effect of zinc fertilization on the mineral nutrition of rice differing in tolerance to zinc deficiency. Plant and Soil. 1985; 87:319-327.
46. Dhaliwal SS, Sadana US, Walia SS, Sidhu SS. Long-term effects of manures and fertilizers on chemical fractions of Fe and Mn and their uptake under rice-wheat cropping system in North-West India. International Journal of Agricultural Science. 2012; 8(1):98-107.
47. Verma TS, Neue HU. Effect of soil salinity level and zinc application on growth, yield, and nutrient composition of rice. Plant and Soil. 1984; 82(1):3-14.